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BREAKDOWN AND CARRYING CAPACITY OF ICE

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Material on the plastic deformation of ice was presented to us in the preceding article. It was shown that the plastic deformation of ice, even in the case of small load, leads in time to breakdown if the temperature of the ice is 0° C.

Under actual conditions, when the load on the ice is great, ice can break immediately after the load is applied. In such cases, plastic deformation does not develop to any marked degree and breakdown is chiefly the result of elastic deformation.

In this article, experimental data is furnished concerning the relation of the load causing breakdown to the thickness of the ice and to the area of load distribution. The experiments were carried out with short-duration loads. The problems touched upon in this report have practical importance and have not yet been investigated to the extent they warrant.

Experimental Method

Experiments with the breakdown of ice were carried out with the equipment described in the preceding article. It permitted application of the same pressure to the ice, with different distribution of the load. This was done by giving the support at the end of the rod a different area in

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different experiments. The supports used were ebonite and metal disks with diameters of 5 and 20 cm, and squares with sides measuring from 20 to 65 cm.

For loads, we used a set of metal blocks weighing from 5 to 80 kg. The loads were applied as rapidly as possible in a short time before breakdown began. The breakdown load was always weighed without weight holders.

Results of the Experiment

After sufficient load had been applied to the ice, radial cracks developed, and irreversible deformation was noted. Cracks developed in the center of the depression and spread outward in a series of radii. The formation of radial cracks does not mean that breakdown will take place immediately thereafter. At the same time, the ice retains capacity to withstand considerably greater weight. Finally, after a certain amount of weight was applied, circular cracks formed, and breakdown took place simultaneously. The development of radial cracks was easily observed, but the circular cracks formed almost instantaneously. The circular cracks were not completely closed, although they did approximate true circles. In some breakdown experiments, with the exception of the main cracks shown schematically in Figure 1 (appended) a fine network of faint radial and circular cracks was noted, covering the entire ice field. Within this area there was not so much as a space of one square centimeter left free of these cracks.

With a given thickness of ice, the load under which breakdown occurred depended on the "specific pressure" on the ice -- that is, on the area of the support through which the pressure was transmitted. Table 1 gives this relationship for ice with a thickness of 1.5 cm.

Table 1

Area of support (sq cm)	Breakdown weight (kg)
20	40
177	44
3900	75

When the area over which loads were distributed was increased 200 fold, the breakdown load increased only about two fold. Figure 1 also shows the results of experiments with ice of other thicknesses.

The breakdown load essentially depends upon the thickness of the ice. In view of the special practical importance of this point, we carried out a large number of experiments to investigate this relationship.

A portion of the experimental data is presented in Table 2.

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Table 2

h cm	P kg	ro cm
0.15	0.5	2.5
0.2	0.9	"
0.45	5	2.7
1.2	32	2.5
1.25	31.2	"
1.35	37	"
1.6	57.2	"
2	92	"
2.45	92	2.2
2.5	147	2.5
1.5 + 0.75 Flaky Ice	92	"
1.45 + 0.35 Flaky Ice	57.2	"
2.3	103	"
3	257	"
3.3	162	"
3.6	220	"
4	345	"
6.5 − 7	707	"
10.5	2416	"
40	30000	~150

The first column lists the thickness of the ice, the second indicates the corresponding breakdown loads, while the third column gives the radius of the support.

The point corresponding to a thickness of ice of 40 cm was obtained by placing various tanks on the ice.

The data in Table 2 is illustrated graphically in Figure 2 (appended). The thickness of the ice is charted on the horizontal axis; the breakdown loads on the vertical axis. Points corresponding to greater thickness of ice are not plotted on this graph since they would not fit into the scale. However, these points, as well as the others, are properly placed in a parabolic relation:

$$P = \alpha h^2$$

where $\alpha = 20$, if P is expressed in kg and h in cm.

Experiments with the breakdown of ice were carried out at widely different temperatures (from 0° C to 20° C). In all cases concurring results were obtained. Apparently, the effect of atmospheric temperature on the breakdown load within these limits was practically nil.

As indicated in experiments with plastic deformation described in the preceding article, under rapid application of the loads, breakdown occurs with distinct deformations corresponding to the given thickness of the ice. From a comparison of the values of the maximum sag causing breakdown in the cases of plastic and of elastic deformation, it appears that the two are about the same, as shown in Table 3.

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Table 3

Thickness of Ice (cm)	Maximum Sag During Elastic Deformation (cm)	Maximum Sag During Plastic Deformation (cm)
1	2 - 3	2 - 3
5	5	5
10	9	-
40	-	14

Thus, the breakdown of ice is determined by the extent of the deformation, both in the case of rapid application of loads and in the case of slow development of plastic deformation under the action of small loads.

From the foregoing, it can be concluded that the extent of the deformation is related to the specific carrying capacity of ice under static loads.

The carrying capacity of ice must be determined by the combined total effect of the elastic and plastic deformations. Figure 3 (appended) shows the development of the total deformation (F). The deformation is charted on the vertical axis; time on the horizontal axis. A load is applied to the ice up to moment t_0. The ice deforms elastically at point f_0. Then, in due time, if the load is not removed, a continuous increase of plastic deformation results. The breakdown point will be determined, in the case of large loads, by large elastic deformation and small plastic deformation which, however, develops very quickly. Under small loads, on the contrary, it is determined by small elastic deformation and large plastic deformation, which develops very slowly. For example in our experiments, ice with a thickness of 40 cm under a weight of 5.5 tons displayed a primary deformation of 14 cm at the end of an 8-day period.

It appears to us that this scheme for investigating deformations provides a solution to the problem of the carrying capacity of ice by showing how its elastic and plastic relation may be calculated. In some of the more simple cases, the carrying capacity of ice may be calculated directly on the basis of material furnished in this and the preceding article. Calculation of other concrete examples would require more detailed knowledge of the effect of the area of distribution of the loads and the shape of the support in relation to the cup-shaped core of the sag.

We were assisted in this work by Ivanov, Kolokol'tsov and Rozhanskaya, scientists of the GUMS. We take this occasion to express to them our appreciation.

Summary

1. Presentation of data on the relation of breakdown load to the thickness of ice with a constant surface distribution of load. It was shown that, with ice from 0.15 to 40 cm thick, the relationship varies as the square of the thickness.

2. Presentation of data on the relation of breakdown load to the area of distribution of load for ice with a thickness of 1.5 cm.

3. It is shown that, with prolonged application of the loads, the carrying capacity of ice is determined by the combined total of elastic and plastic deformation.

[Appended figures follow]

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APPENDED FIGURES

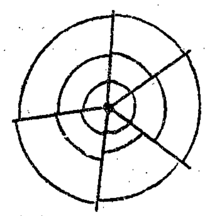

Figure 1

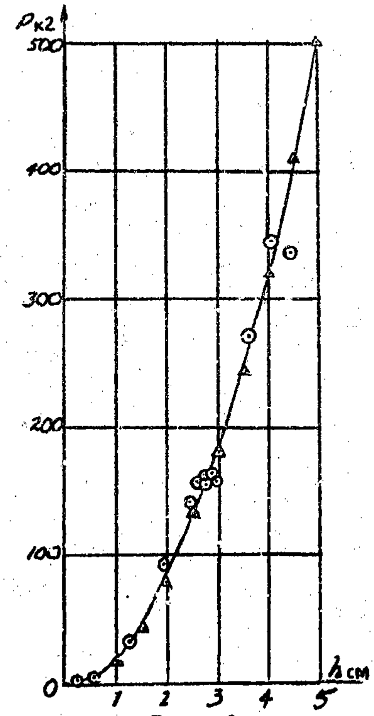

Figure 2

Circles - Experimental data.
Triangles - Parabolic points

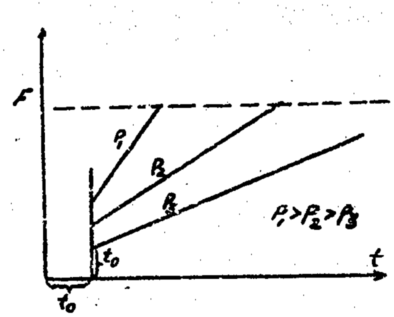

Figure 3

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